THE UNIVERSITY OF TEXAS AT EL PASO

Cygnus Enhancement Pod Design Team

NG / UTEP Final Deliverable

Agenda

- Team introduction
- Project Schedule
- Mission Overview
- Concept of Operations
- System Requirements Overview
- Requirement breakdown
- Design Concept
- Trade Studies
- Risk Assessment
- Requirement Flow down
- Requirement Verification
- Requirement Metrics
- TBX Management
- Integration and Test
- Requirements V&V

Team Introduction

Aldo Montoya
Aerospace Engineering

Isaac Garcia
Aerospace Engineering

Vania Montero
Aerospace Engineering

Jose Vega
Industrial & Systems
Engineering

Angel Rodriguez
Industrial & Systems
Engineering

Carlton Melver
Industrial & Systems
Engineering

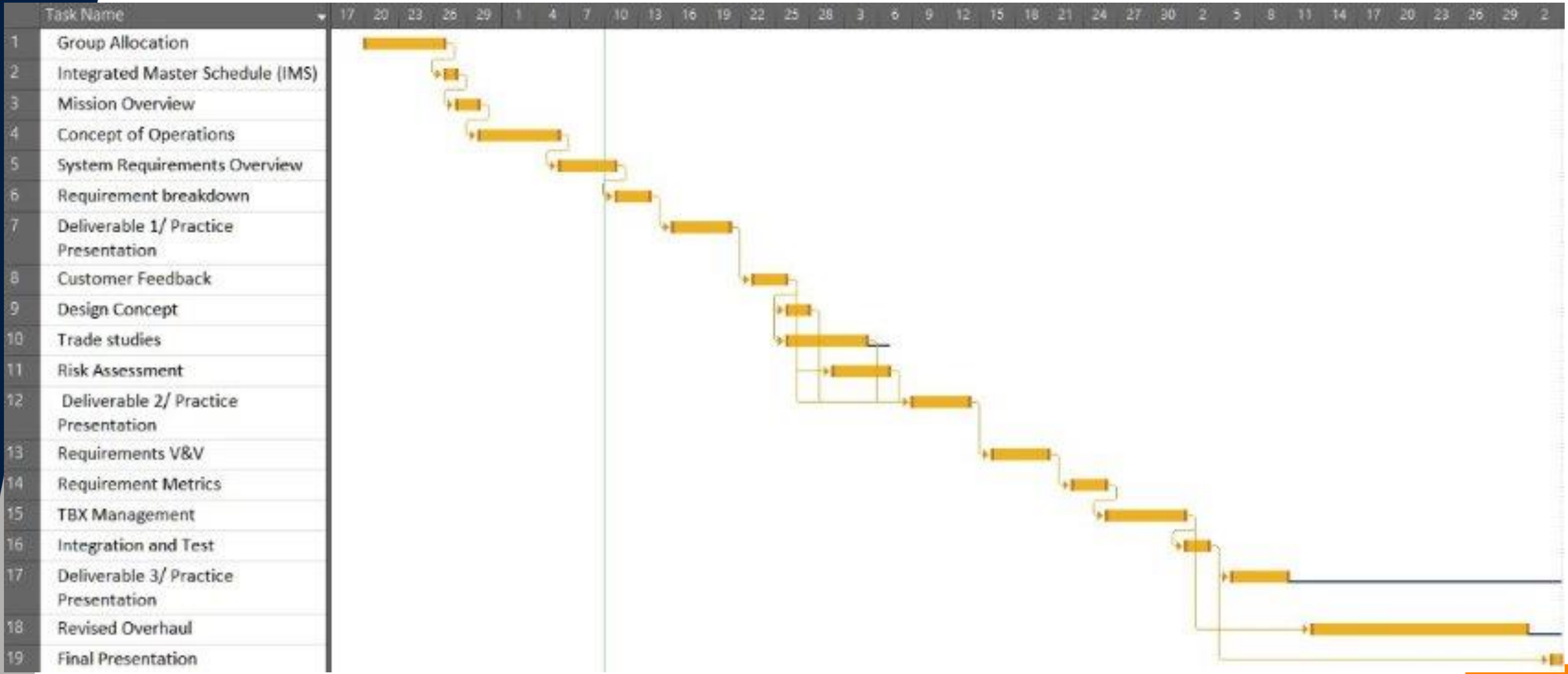
Mission Overview

The Cygnus Enhancement Pod (CEP) is a recoverable external cargo capsule designed to safely return from the International Space Station to Earth through controlled atmospheric reentry and recovery operations while transporting payloads.

The CEP is meant to launch from Earth attached to Cygnus, and when it returns from the ISS it will separate from Cygnus and follow a different trajectory

While current Cygnus missions are not designed for safe cargo return, a need is created for a lightweight recoverable vehicle capable of surviving reentry and achieving a safe landing.

Project Schedule



	Task Name
1	Group Allocation
2	Integrated Master Schedule (IMS)
3	Mission Overview
4	Concept of Operations
5	System Requirements Overview
6	Requirement breakdown
7	Deliverable 1/ Practice Presentation
8	Customer Feedback
9	Design Concept
10	Trade studies
11	Risk Assessment
12	Deliverable 2/ Practice Presentation
13	Requirements V&V
14	Requirement Metrics
15	TBX Management
16	Integration and Test
17	Deliverable 3/ Practice Presentation
18	Revised Overhaul
19	Final Presentation

CONOPS: Cygnus Detachable Re-entry Capsule

Enable return of critical payloads from ISS via a detachable capsule integrated with Cygnus, ensuring safe re-entry and recovery

Telemetry, Control and Ranging

1. Nominal Operations (ISS docked)
2. De-orbit Prep and Detachment
3. Capsule Separation Mechanism
4. Re-Entry and Descent
5. Recovery

System Requirements

R1	The CEP shall return cargo safely from the ISS to Earth.
R1.1	The system shall transport cargo from the ISS to earth safely.
R1.1.1	The CEP shall protect cargo from orbit, re-entry and impact.
R1.1.1.1	The CEP shall maintain structural integrity when carrying cargo from 0 up to 72 lbs.
R1.1.2	The CEP shall protect cargo from orbit, re-entry and impact.
R1.1.3	The CEP shall store a cargo volume of 11x24.5x18.5 inches.
R1.2	The CEP shall separate from the Cygnus spacecraft.
R1.2.1	The CEP shall mount to the Cygnus spacecraft via the PFRAM attachment system.
R1.2.2	The CEP shall remain securely attached to the PFRAM without permanent deformation.
R1.2.3	The CEP shall provide electrical connections for power and data exchange with the Cygnus spacecraft.
R1.2.4	The CEP shall separate from cygnus without damaging either the CEP or affecting Cygnus trajectory.

R1.3	The CEP shall provide power to the required internal systems during the return mission.
R1.3.1	The CEP shall provide power to systems up to 75W for 6 hours.
R1.4	The CEP shall Re-enter the atmosphere and descend to target region.
R1.4.1	The CEP shall maintain an aerodynamically stable orientation during atmospheric entry without uncontrolled tumbling.
R1.4.2	The CEP shall support recovery operations within a designated CONUS recovery region.
R1.4.3	The CEP shall maintain cargo compartment temperature within payload allowable limits during reentry and recovery.
R1.5	The CEP shall Land safely and be recovered within 6 hours.
R1.5.1	The CEP shall remain buoyant and upright after splashdown until recovery operations begin.
R1.5.2	The CEP shall transmit recovery location data for retrieval operations within 6 hours after landing.

Concept Design

Parachute – After re-entry and guided trajectory, a parachute will deploy for the final descending phase.

Flaps – Flaps will remain retracted during mission until atmosphere re-entry, then will be deployed via automation using speed and temperature sensors sending data to an actuator.

Battery – Power supply will be available upon launch but will be used only after Cygnus separates from ISS for an optimized power usage.

PFRAM – Separation Mechanism System used to detach the CEP from Cygnus before it starts re-entry phase..

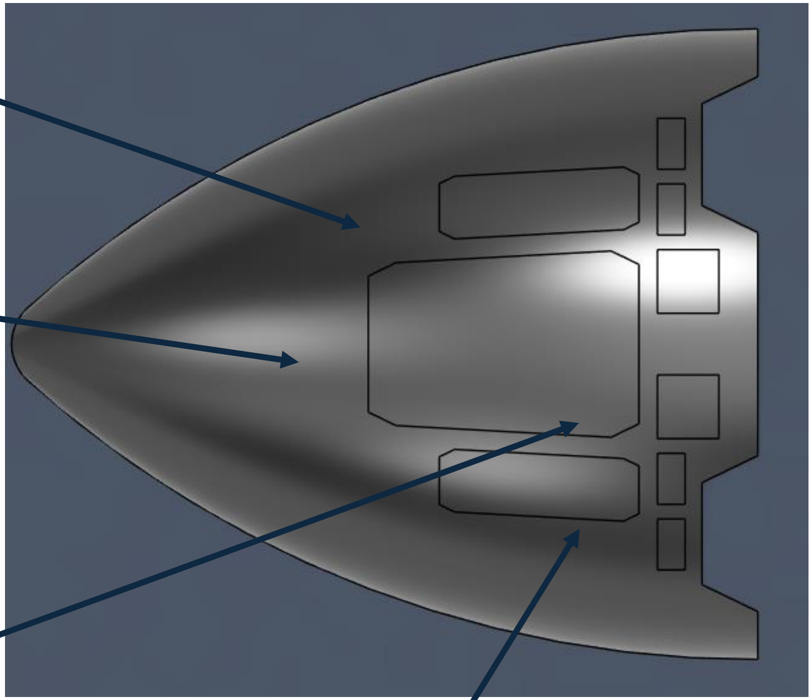
Cargo Bay – Cargo compartment bay used for payload return from ISS. It can be accessed via ISS Robotic Arm, or manually.

Heat Shield – Thermal Protection System to protect payload and overall structure from risky re-entry temperatures.

Gyroscopes – Automated gyroscopes that will be activated after re-entry to aid descent before parachute deployment.

Add more pictures

Design Concept – CAD Model



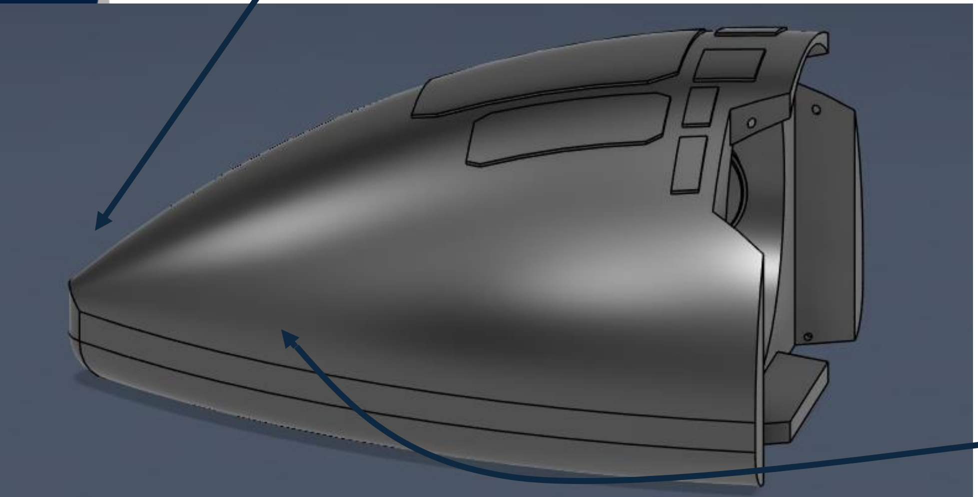
[Payload]
Cargo Compartment(Temperature/Pressure Controlled)

[Control]
Parachute Bay

[Structural]
Thermal Protection System at Tip

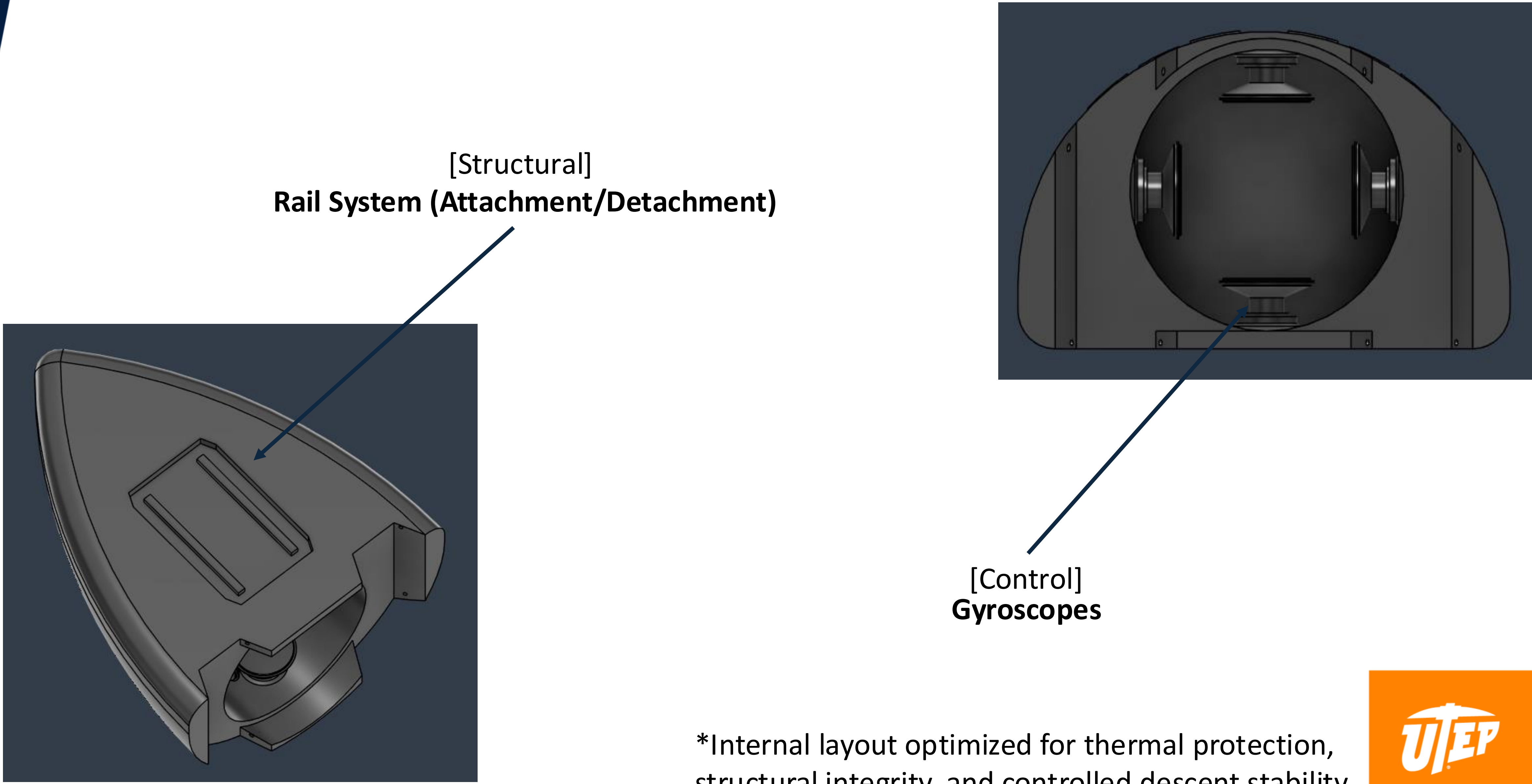
[Control]
Battery and Avionics Bay

[Payload]
Recovery Beacon



[Structural]
Thermal Protection System Underbelly

Design Concept – CAD Model



[Structural]
Rail System (Attachment/Detachment)

[Control]
Gyroscopes

*Internal layout optimized for thermal protection, structural integrity, and controlled descent stability.

Trade Studies – Pod Body Materials

Material	Thermal (Operating Temperature	Structural (Yield Strength, Tensile Strength)	Cost	Manufacturing (Machining, Welding, Stamping)	Density	Trade Score (Highest Number Wins)
6016-T6 Aluminum	≤ 320°F (2)	≥ 21.75 kpsi ≥ 36.26 kpsi (3)	$1.08-1.68 per lb. (5)	(4)	.0975 lb./in^3 (3)	3
Ti (6Al-4V) Titanium	**≤ 600°F (4)**	**≥ 120 kpsi** **≥ 130 kpsi** **(4)**	**$10-16 per lb.** **(2)**	**(3)**	**0.160 lb./in^3** **(3)**	**3.45**
Carbon Reinforced Polymer	≤ 482°F (3)	N/A (cannot lose form) 580 kpsi (5)	$15-30 per lb. (1)	(2)	0.065 lb./in^3 (4)	3.15

Material	**Thermal (Operating Temperature**	**Structural (Yield Strength, Tensile Strength)**	**Cost**	**Manufacturing (Machining, Welding, Stamping)**	**Density**	**Trade Score (Highest Number Wins)**
Aluminum-Lithium Alloy (Al-Li)	≤ 350°F (177°C) (3)	Yield: ~400–500 MPa Tensile: ~450–600 MPa (4)	$10–20/lb (3)	Moderate – machining & forming OK, welding harder (3)	~2.6 g/cm³ (0.094 lb/in³) (5)	3.6–3.8
Inconel (Nickel superalloy)	**≤ 1800°F (982°C) (5)**	**Yield: ~600–1000 MPa Tensile: ~900–1400 MPa (5)**	**$20–40/lb (1)**	**Difficult – hard to machine, high temp forming (2)**	**~8.4 g/cm³ (0.30 lb/in³) (1)**	**3.2–3.4**
Stainless Steel	≤ 1500°F (815°C) (4)	Yield: ~200–300 MPa Tensile: ~500–700 MPa (3)	$2–5/lb (5)	Easy – weldable, widely available (5)	~8.0 g/cm³ (0.289 lb/in³) (1)	3.4

Trade Studies – Internal Materials

Material	**Thermal (Operating Temperature)**	**Structural (Yield Strength, Tensile Strength)**	**Cost**	**Manufacturing (Machining, Welding, Stamping)**	**Density**	**Trade Score (Highest Number Wins)**
Kevlar	≤ 800°F **(5)**	N/A (composite fiber) ≥ 525 KPSI tensile strength **(5)**	\$20–40 per lb. **(1)**	Composite layup / fiber weaving (2)	0.052 lbs./in^3 (5)	4.1
Nomex	**≤ 700°F (5)**	**≈ 10–15 kpsi tensile strength (2)**	**\$18–35 per lb. (1)**	**Honeycomb fabrication / bonding (3)**	**0.030 lbs./in^3 (5)**	**3.45**
High Density Polyethylene	≤ 230°F **(1)**	≥ 3–4 kpsi tensile strength **(1)**	\$0.70–1.20 per lb. (5)	Excellent machinability / injection molding (5)	0.034 lbs./in^3 (5)	2.6
Silicone	**≤ 600°F (4)**	**≥ 1–2 kpsi tensile strength (1)**	**\$6–12 per lb. (3)**	**Molded elastomer fabrication (4)**	**0.040 lbs./in^3 (4)**	**3.1**

Trade Studies – Insulation Materials

Material	Thermal Conductivity (Lower the better)	Max Temp	Cost $/ft^2	Manufacturing	Density	Trade Score
Aerogel (Airloy® X116)	.01387 BTU/(h •ft •°F) **(5)**	≤ 300°F **(2)**	$1728 (One tile covers 7.5 in at $90) **(1)**	**(3)**	0.0032 lbs/in^3 **(5)**	**3.45**
Ceramic Fiber Blanket PCW Grade 3000°F	0.0809 BTU/(h •ft •°F) **(3)**	≤ 1112°F **(5)**	$2-5 dollars (2ft x24ft at 2,375-5345) **(4)**	**(5)**	.00347 lb/in^3 **(4)**	**4**
Multi-Layer Insulation (MLI)	**~0.0005–0.0015 BTU/(h·ft·°F) (5)**	**≤ 932°F (4)**	**~$8–20/ft^2 (3)**	(2)	**~0.0009–0.0015 lb/in^3 (5)**	**4**
Fiberglass Insulation	**~0.020–0.030 BTU/(h·ft·°F) (4)**	**≤ 1000°F (4)**	**~$0.50–2/ft^2 (5)**	**(5)**	**~0.0018–0.0025 lb/in^3 (5)**	**4.6**
Polymide foam	**~0.018–0.025 BTU/(h·ft·°F) (4)**	**≤ 600°F (3)**	**~$10–25/ft^2 (3)**	**(4)**	**~0.0007–0.0015 lb/in^3 (5)**	**3.8**

Trade Studies – Selected Materials

Trade Studies – Atachment/Detachment

Metric	Max Load Capacity (kN)	Safety Factor	Separation Velocity (m/s)	Shock Level (g's)	Separation Time (ms)	Failure Rate (%)	Trade Score
Rail system	10–15 (4)	2.0–2.5 (4)	0.5–1.0 (5)	5–10 (5)	200–500 (4)	1–3% (3)	4.2
Frangible bolt	20–30 (5)	2.5–3.0 (5)	2–5 (2)	1000+ (1)	<10 (5)	<1% (5)	3.8
Motorized latch PFRAM	8–12 (4)	2.0–2.5 (4)	0.5–1.0 (5)	<5 (5)	500–1000 (3)	2–5% (3)	4.1

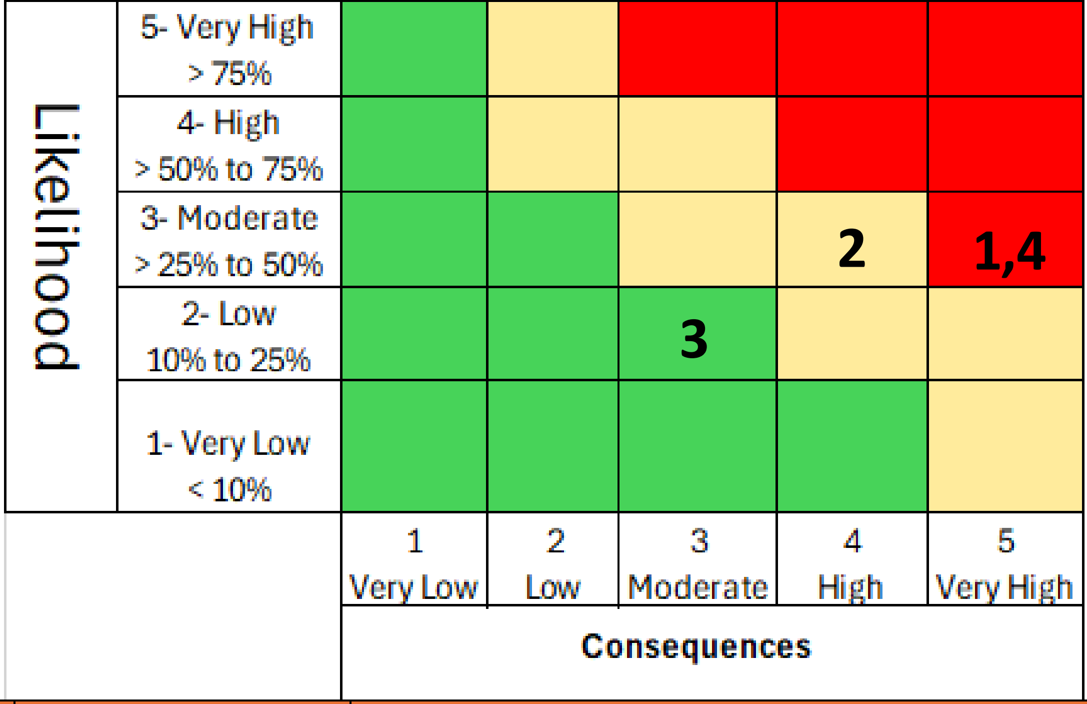
Trade Studies - Gyroscopes

Material / System	Accuracy / Drift Performance	Power Usage	Cost $/Unit	Manufacturing / Integration	Density / Size / Weight	Trade Score
MEMS Gyroscope / IMU	Good short-duration attitude sensing; higher drift than optical gyros; widely used where SWaP matters (4)	Low power; favorable for battery-limited pods (5)	Lowest cost of the three; industrial units can range from hundreds to low thousands, tactical units higher (5)	Easiest to integrate; compact solid-state electronics; mature embedded interfaces (5)	Smallest and lightest option; best CSWaP fit (5)	4.8
Fiber Optic Gyroscope (FOG)	Better drift/accuracy than MEMS; strong option when precision is more important than SWaP (5)	Higher power than MEMS (3)	Much higher cost than MEMS (2)	More integration burden; larger and more complex packaging (3)	Larger and heavier than MEMS, but generally smaller/cheaper than high-end RLG (3)	3.4
Ring Laser Gyroscope (RLG)	Very high performance and very low drift; traditionally used in top-end inertial navigation (5)	Higher power burden (2)	Highest cost / least practical for this pod (1)	Most complex and least practical integration for a student pod-scale system (2)	Heavier / larger system burden than MEMS (2)	2.8

SWaP: Size, Weight and Power
CSWaP: Cost, Size, Weight and Power

Risk Assessment

Risk ID	Risk	Owner	Reason	Consequence	Risk Level
1	Thermal Protection Failure	Thermal System Engineering Team	Heatshield damage, extreme re-entry heating	Vehicle Burn through during re-entry, loss of critical payload.	5,3
2	Parachute Deployment Failure	Entry, Decent and Landing systems Team	Mechanical or Gyro-Shock failure, line tangling of deployment or a timing error.	Hard impact or fatal landing of pod.	4,3
3	Structural Integrity Failure	Design Engineering Team	Excessive Aerodynamic load, material fatigue, structural design weakness.	Capsule breakup or deformation during re-entry.	3,2
4	Incorrect Trajectory Failure	Trajectory Engineering Team	Too much delta V or miscalculation	Wrong orientation, heat shield not facing airflow leading to incorrect landing area.	5,3

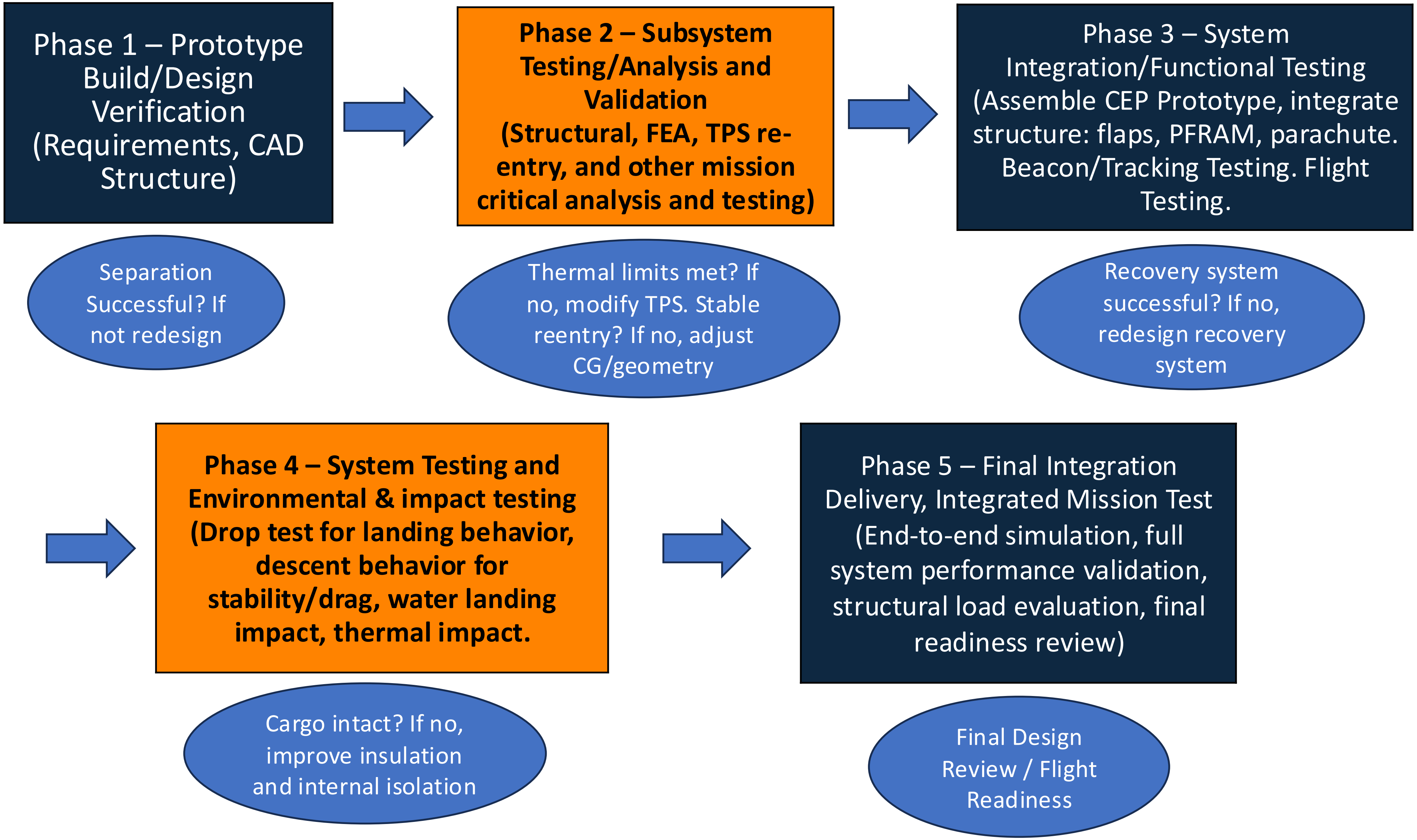


Likelihood						
	5- Very High > 75%	🟩	🟨	🟥	🟥	🟥
	4- High > 50% to 75%	🟩	🟨	🟨	🟥	🟥
	3- Moderate > 25% to 50%	🟩	🟩	🟨	🟨 2	🟥 1,4
	2- Low 10% to 25%	🟩	🟩	🟩 3	🟨	🟨
	1- Very Low < 10%	🟩	🟩	🟩	🟩	🟨
		1 Very Low	2 Low	3 Moderate	4 High	5 Very High

Consequences

Risk ID	Risk	Owner	Mitigation
1	Thermal protection failure	Thermal Engineering Team	Provide sufficient Thermal Protection System materials with redundant sacrificial thermal layers.
2	Parachute deployment failure	Entry, Decent and landing team	Include multiple Parachutes in separate housing and staged deployment boxes.
3	Structural Integrity Failure	Design Engineering Team	Have High-strength alloys and structural testing.
4	Incorrect Trajectory Failure	Trajectory Engineering Team	Autonomous guidance & trajectory correction by adding propellers.

Integration and Test



Phase 1 – Prototype Build/Design Verification (Requirements, CAD Structure)

Separation Successful? If not redesign

Phase 2 – Subsystem Testing/Analysis and Validation (Structural, FEA, TPS re-entry, and other mission critical analysis and testing)

Thermal limits met? If no, modify TPS. Stable reentry? If no, adjust CG/geometry

Phase 3 – System Integration/Functional Testing (Assemble CEP Prototype, integrate structure: flaps, PFRAM, parachute. Beacon/Tracking Testing. Flight Testing.

Recovery system successful? If no, redesign recovery system

Phase 4 – System Testing and Environmental & impact testing (Drop test for landing behavior, descent behavior for stability/drag, water landing impact, thermal impact.

Cargo intact? If no, improve insulation and internal isolation

Phase 5 – Final Integration Delivery, Integrated Mission Test (End-to-end simulation, full system performance validation, structural load evaluation, final readiness review)

Final Design Review / Flight Readiness

TBX Management

ID	Item	Description	Resolution Plan
TBD-01	Cargo Bay CAD	Cargo bay was sized by requirement, but detailed CAD/layout is incomplete	Create detailed CAD showing cargo tray, restraints, insulation, hatch access, and sensor placement
TBD-02	Electrical Power Interface	Power requirement is defined as 75 W for 6 hr, but power interface with cygnus has not been fully defined	Complete power budget, calculate Wh required. Define connection to Cynus power distribution.
TBD-03	Avionics Architecture	IMU/GPS/beacon were discussed, but full avionics design is incomplete	Define avionics block diagram, sensor list, data flow, and mounting locations
TBD-04	Cygnus Power Interface	CEP power-from-Cygnus concept is not fully defined	Identify expected voltage/current interface and connection method through PFRAM.
TBD-05	Electrical Disconnect	Mechanical separation is discussed, but safe electrical disconnect is not detailed	Select breakaway connector concept and define disconnect sequence
TBD-06	Mechanism Final Design	Rail-Latch system concept exists, but detailed mechanism CAD and actuation method are incomplete	Finalize rail/latch geometry, release actuator, springs, clearances, and failure modes

ID	Item	Why Revise	Revision Plan
TBR-01	Mass Budget	Current mass is preliminary and not based on completed CAD	Update mass using detailed CAD and actual materials
TBR-02	Power Requirement	75 W for 6 hr may not include avionics, beacon, sensors, heaters, and deployment systems	Revise after full electrical load analysis
TBR-03	Requirement Flowdown	Some requirements still need stronger connection to mechanism/power/avionics	Update requirements to include cargo bay, power interface, avionics, and separation sequence
TBR-04	Integration & Test Plan	Test plan exists but does not fully include avionics/power/interface testing	Add battery test, connector disconnect test, beacon test, and end-to-end mission demonstration
TBR-05	Concept CAD	Current CAD does not fully represent all internal systems	Revise CAD to include cargo bay, battery, avionics, wiring path, PFRAM interface, and recovery hardware

Requirements Verification & Validation

Verification confirms each requirement is met through inspection, demonstration, test, or analysis, while validation confirms the CEP satisfies the mission need of safely returning cargo.

Req ID	Requirement	Method (I/D/T/A)	Verification	Validation
R1.1.1	Cargo capacity	I, A	Inspect CAD/internal bay and confirm mass budget supports 72 lb and 11″ × 24.5″ × 18.5″ cargo	Confirms CEP can support the intended ISS return-cargo mission
R1.1.2	**Cargo protection**	**T**	**Perform structural/load analysis and representative drop or shock test**	**Returned cargo remains usable after simulated return mission**
R1.1.3	Cargo environment	A	Thermal analysis and sensor-based thermal test of cargo bay	Temperature-sensitive payloads remain within acceptable mission conditions
R1.1.4	**Power support**	**D, T**	**Power budget + battery discharge test + power delivery demo**	**CEP can support critical functions through separation, descent, landing, and recovery**
R1.2.1	Mechanical interface	I	Inspect PFRAM geometry and analyze interface loads	CEP can integrate with Cygnus without disrupting nominal operations

R1.2.2	Electrical interface	I, D	Inspect connector design and demonstrate power/data continuity	Electrical interface supports mission operations before safe separation
R1.2.3	Separation	A, D, T	Clearance analysis, release demonstration, and ground separation test	CEP separates without recontact or interference with Cygnus mission
R1.3.1	Reentry survivability	A	Thermal/structural reentry analysis	CEP concept remains feasible for safely returning cargo through reentry
R1.3.2	Stability	A	Aerodynamic/trajectory simulation and flap deployment demonstration	Pod remains stable enough to support recovery-zone targeting
R1.3.3	Descent control	A, D	Trajectory simulation using mass, area, Cd, and descent assumptions	CEP can reach the intended recovery region without propulsion
R1.4.1	Landing safety	T	Landing load analysis and drop/impact test	Cargo remains usable and recovery team can safely approach the pod
R1.4.2	Location reporting	D	Demonstrate GPS/beacon activation and signal transmission	Recovery team can locate the pod within operational recovery needs
R1.4.3	Recovery time	A	Recovery timeline analysis and operational recovery walkthrough	CEP can be recovered within the 6-hour mission requirement

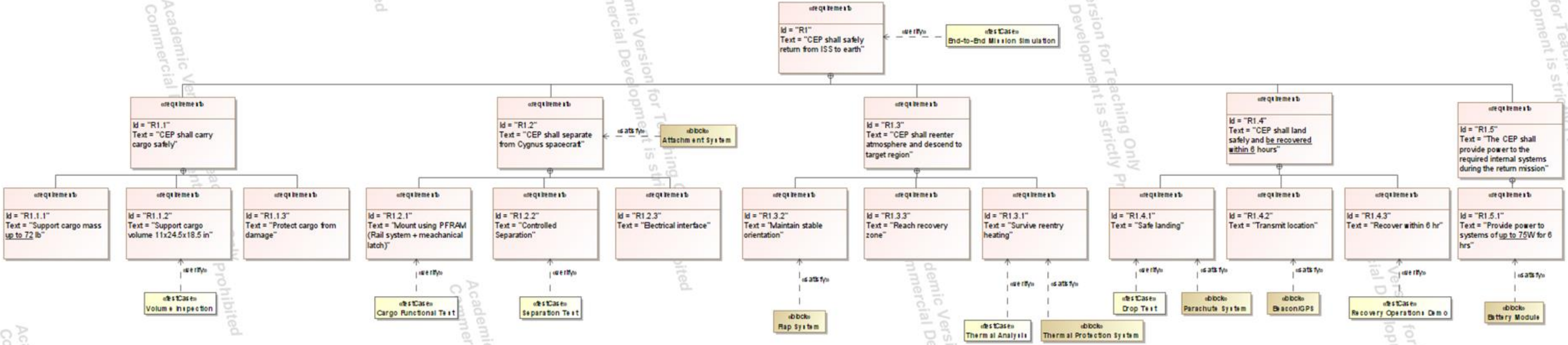
THE UNIVERSITY OF TEXAS AT EL PASO

Q&A

THE UNIVERSITY OF TEXAS AT EL PASO

Backup Slides

Requirement Flowdown



«requirement»
Id = "R1"
Text = "CEP shall safely return from ISS to earth"

«verify»
«testCase»
End-to-End Mission Simulation

«requirement»
Id = "R1.1"
Text = "CEP shall carry cargo safely"

«requirement»
Id = "R1.1.1"
Text = "Support cargo mass up to 72 lb"

«requirement»
Id = "R1.1.2"
Text = "Support cargo volume 11x24.5x18.5 in"

«verify»
«testCase»
Volume Inspection

«requirement»
Id = "R1.1.3"
Text = "Protect cargo from damage"

«requirement»
Id = "R1.2"
Text = "CEP shall separate from Cygnus spacecraft"

«satisfy»
«block»
Attachment System

«requirement»
Id = "R1.2.1"
Text = "Mount using PFRAM (Rail system + meachanical latch)"

«verify»
«testCase»
Cargo Functional Test

«requirement»
Id = "R1.2.2"
Text = "Controlled Separation"

«verify»
«testCase»
Separation Test

«requirement»
Id = "R1.2.3"
Text = "Electrical interface"

«requirement»
Id = "R1.3"
Text = "CEP shall reenter atmosphere and descend to target region"

«requirement»
Id = "R1.3.2"
Text = "Maintain stable orientation"

«satisfy»
«block»
Flap System

«requirement»
Id = "R1.3.3"
Text = "Reach recovery zone"

«requirement»
Id = "R1.3.1"
Text = "Survive reentry heating"

«verify»
«testCase»
Thermal Analysis

«satisfy»
«block»
Thermal Protection System

«requirement»
Id = "R1.4"
Text = "CEP shall land safely and be recovered within 6 hours"

«requirement»
Id = "R1.4.1"
Text = "Safe landing"

«verify»
«testCase»
Drop Test

«satisfy»
«block»
Parachute System

«requirement»
Id = "R1.4.2"
Text = "Transmit location"

«satisfy»
«block»
Beacon/GPS

«requirement»
Id = "R1.4.3"
Text = "Recover within 6 hr"

«verify»
«testCase»
Recovery Operations Demo

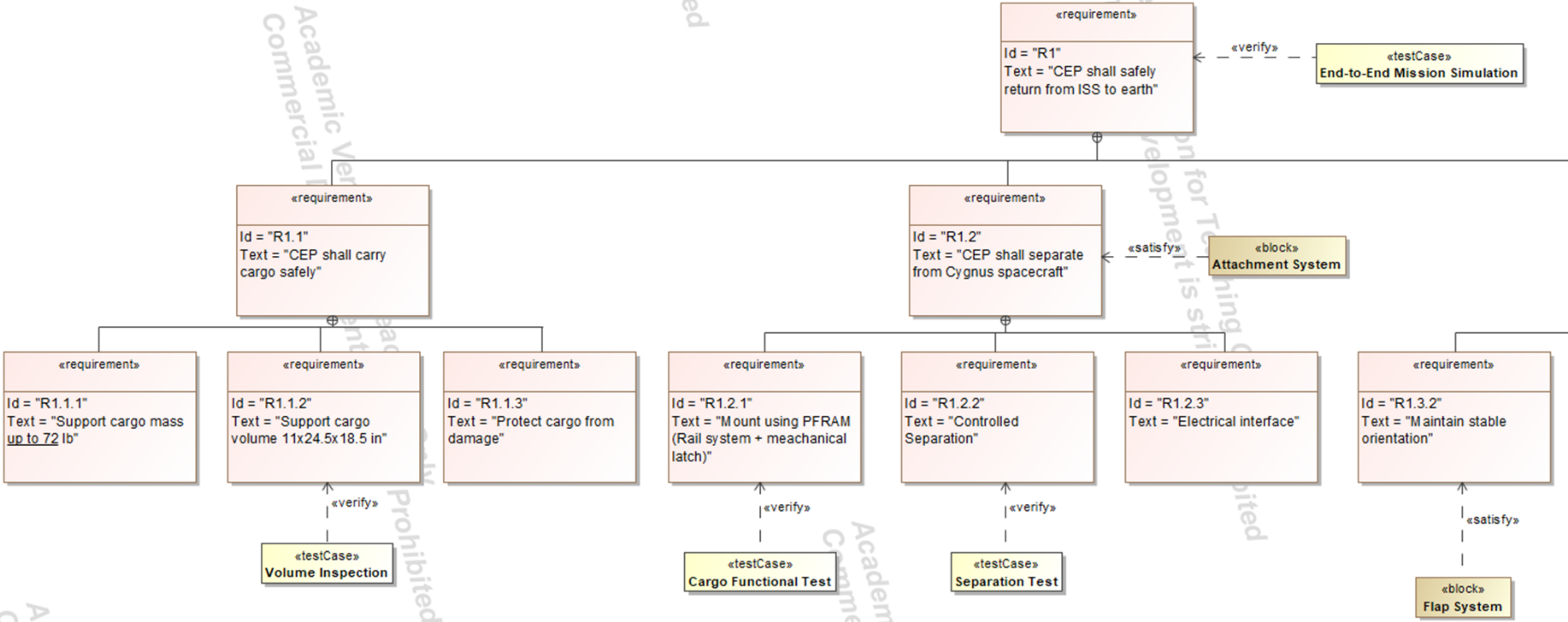
«requirement»
Id = "R1.5"
Text = "The CEP shall provide power to the required internal systems during the return mission"

«requirement»
Id = "R1.5.1"
Text = "Provide power to systems of up to 75W for 6 hrs"

«satisfy»
«block»
Battery Module

CEP – Integrated Build, Test, and Verification Flow

Test Flow Stage	Phase / Activity	Main Test Items	Pass/Fail Decision	Required Resources
1. Design Verification	Phase 1 – Prototype Build	Requirements traceability, CAD model in Fusion 360, structural layout of pod + rails, mass properties, CG/inertia, flaps, parachute housing, PFRAM interface	Separation interface successful? If no, redesign interface	CAD software, 3D printer
2. Analysis & Validation	**Phase 2 – Subsystem Testing**	**Structural loads/FEA, TPS reentry heating, aerodynamic stability, separation mechanism test, flap deployment test, parachute deployment test**	**Thermal limits met? If no, modify TPS. Stable reentry? If no, adjust CG/geometry**	**FEA/thermal tools, sensors, parachute test rig**
3. Functional Testing	Phase 3 – System Integration	Assemble CEP prototype, integrate structure, flaps, PFRAM, parachute, beacon/tracking system, flight system test	Recovery system successful? If no, redesign recovery system	Prototype hardware, sensors, tracking beacon
4. Environmental & Impact Testing	**Phase 4 – System Testing**	**Drop test for landing behavior, descent behavior for stability/drag, water landing impact, cargo integrity, shock + thermal evaluation**	**Cargo intact? If no, improve insulation and internal isolation**	**Drop test area, water impact test area, temperature/velocity sensors**
5. Integrated Mission Test	Phase 5 – Final Integration Delivery	End-to-end simulation, full system performance validation, structural load evaluation, final readiness review	Final Design Review / Flight Readiness	Wind tunnel if available, final prototype, test documentation



«requirement»
Id = "R1"
Text = "CEP shall safely return from ISS to earth"

«verify»

«testCase»
End-to-End Mission Simulation

«requirement»
Id = "R1.1"
Text = "CEP shall carry cargo safely"

«requirement»
Id = "R1.2"
Text = "CEP shall separate from Cygnus spacecraft"

«satisfy»

«block»
Attachment System

«requirement»
Id = "R1.1.1"
Text = "Support cargo mass up to 72 lb"

«requirement»
Id = "R1.1.2"
Text = "Support cargo volume 11x24.5x18.5 in"

«verify»

«testCase»
Volume Inspection

«requirement»
Id = "R1.1.3"
Text = "Protect cargo from damage"

«requirement»
Id = "R1.2.1"
Text = "Mount using PFRAM (Rail system + meachanical latch)"

«verify»

«testCase»
Cargo Functional Test

«requirement»
Id = "R1.2.2"
Text = "Controlled Separation"

«verify»

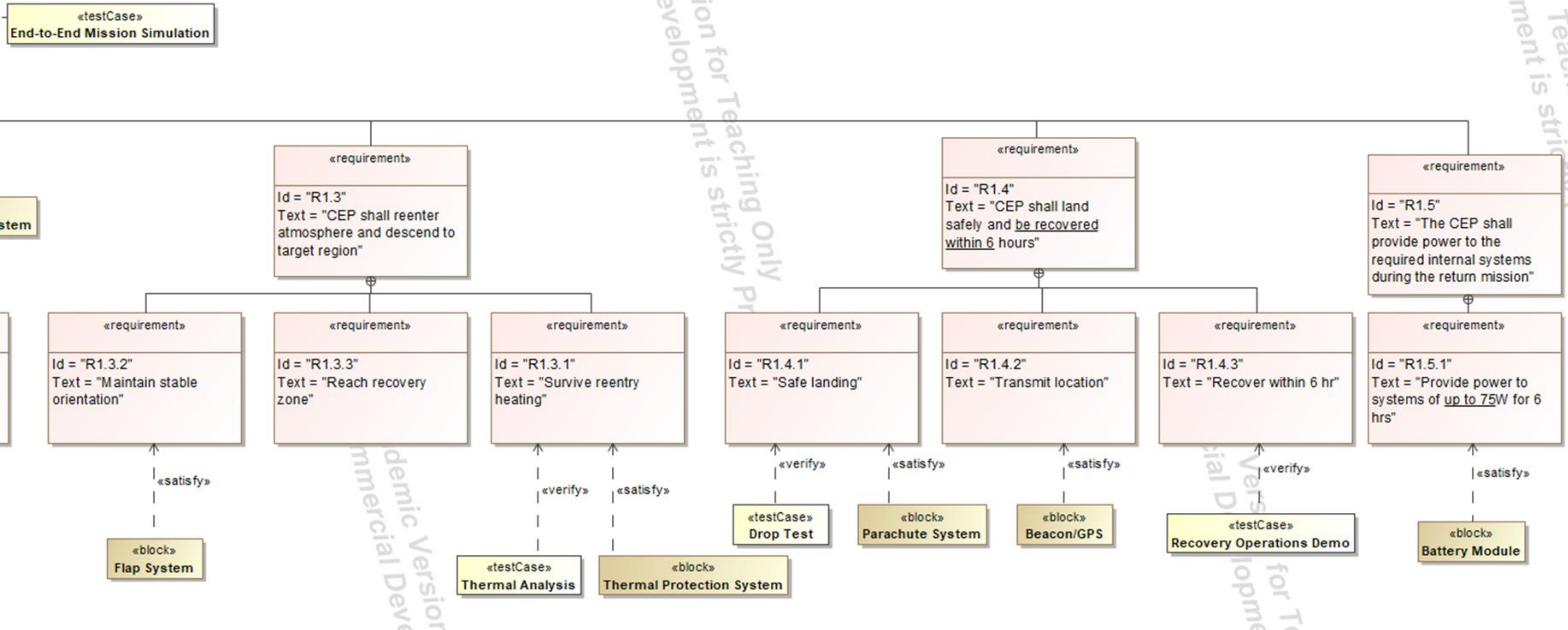
«testCase»
Separation Test

«requirement»
Id = "R1.2.3"
Text = "Electrical interface"

«requirement»
Id = "R1.3.2"
Text = "Maintain stable orientation"

«satisfy»

«block»
Flap System



«testCase»
End-to-End Mission Simulation

stem

«requirement»
Id = "R1.3"
Text = "CEP shall reenter atmosphere and descend to target region"

«requirement»
Id = "R1.3.2"
Text = "Maintain stable orientation"

«satisfy» «block» **Flap System**

«requirement»
Id = "R1.3.3"
Text = "Reach recovery zone"

«requirement»
Id = "R1.3.1"
Text = "Survive reentry heating"

«verify» «testCase» **Thermal Analysis**

«satisfy» «block» **Thermal Protection System**

«requirement»
Id = "R1.4"
Text = "CEP shall land safely and be recovered within 6 hours"

«requirement»
Id = "R1.4.1"
Text = "Safe landing"

«verify» «testCase» **Drop Test**

«satisfy» «block» **Parachute System**

«requirement»
Id = "R1.4.2"
Text = "Transmit location"

«satisfy» «block» **Beacon/GPS**

«requirement»
Id = "R1.4.3"
Text = "Recover within 6 hr"

«verify» «testCase» **Recovery Operations Demo**

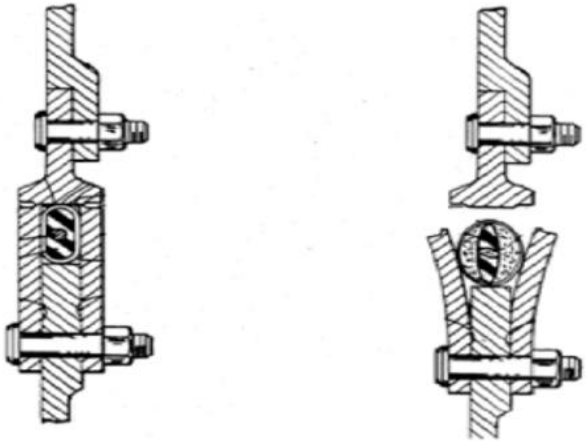
«requirement»
Id = "R1.5"
Text = "The CEP shall provide power to the required internal systems during the return mission"

«requirement»
Id = "R1.5.1"
Text = "Provide power to systems of up to 75W for 6 hrs"

«satisfy» «block» **Battery Module**

Trade Studies – Attachment/Detachment

Profiled Rail System
CEP slides along guided rails and is released using springs or actuators.



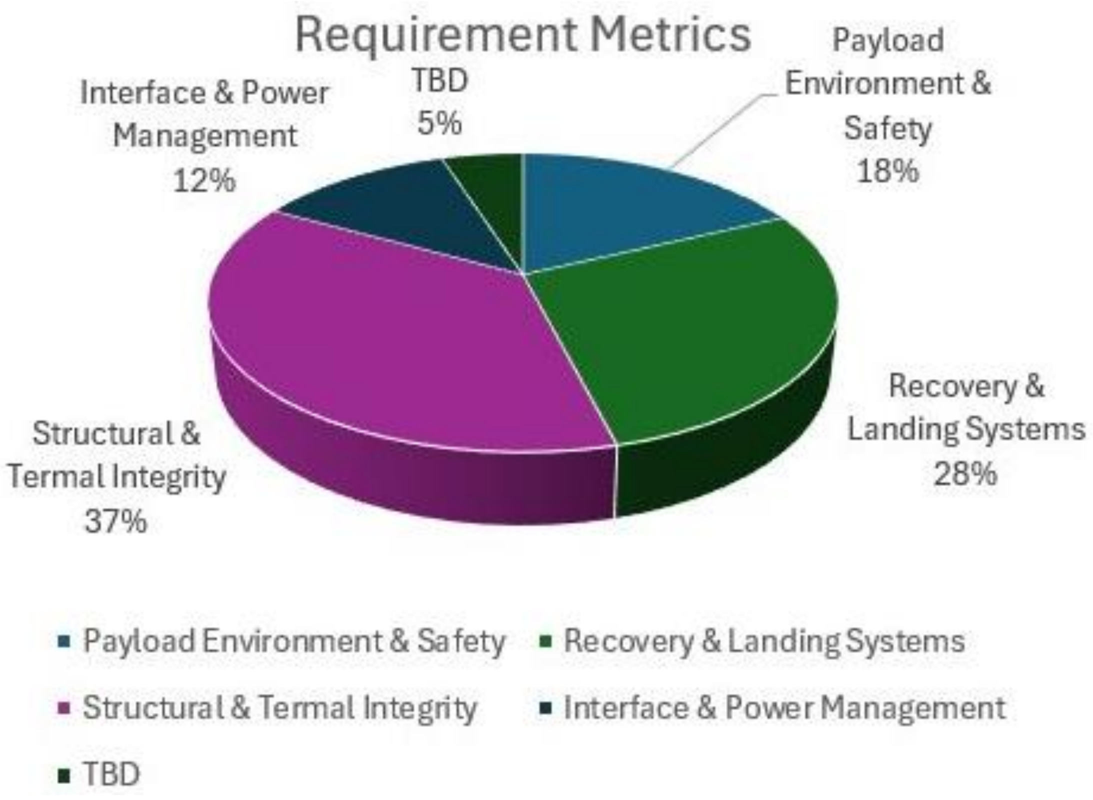
Frangible Bolt
Bolts are broken using pyrotechnics, and springs push the CEP away.

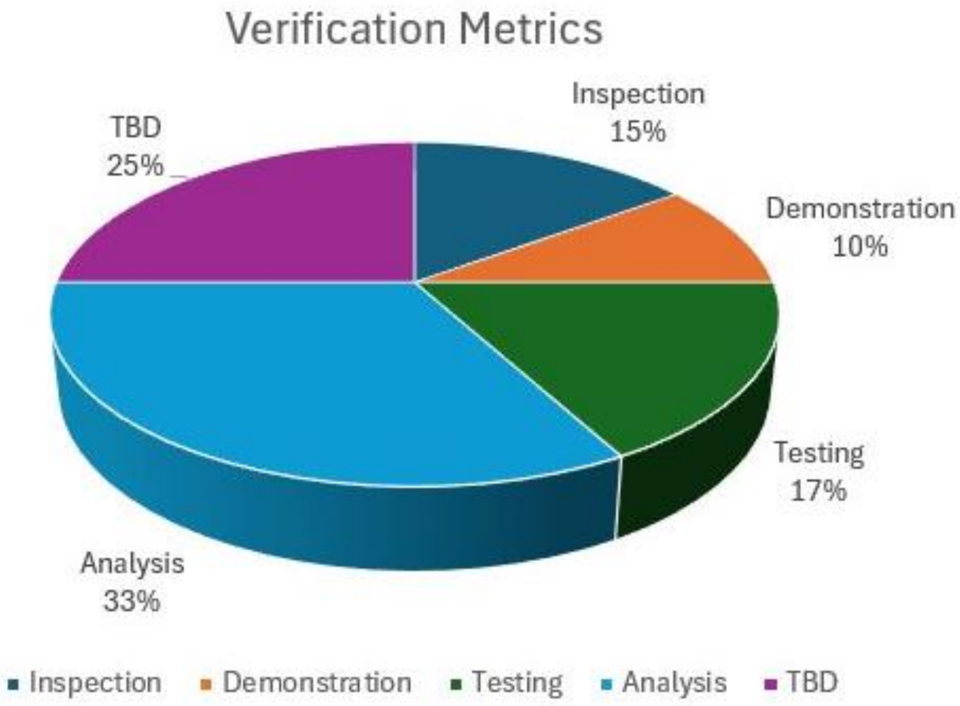
(Diegelman et al., 2016)

Trade Studies – Propeller Design

Prop Type	Efficiency	Battery Usage	Motor Lifespan	Control Response	Manufacturing	Trade Score
3-Bladed Prop	High efficiency Lower torque required Well-optimized aerodynamics (5)	Low power draw Efficient thrust per watt Minimal battery load (5)	Lower torque → less motor stress Moderate vibration Long operational life (4)	Fast RPM response Quick thrust changes Good for corrections (5)	Simple geometry Mass-produced Low cost & risk (5)	4.4 – 4.5
Toroidal Prop	Reduced tip vortices But higher torque required Lower thrust-per-watt (2–3)	Higher power draw Increased battery demand Less efficient operation (2)	Higher torque load on motor Lower vibration (benefit) Moderate lifespan (3)	Slower acceleration/deceleration Poor transient response Less effective for control (2)	Complex geometry Harder to manufacture Higher cost & integration risk (2–3)	2.3 – 3.0

Requirement Verification





Design Concept – Rail System

Purpose

- Attaches cargo return pod to host spacecraft
- Provides structural support and alignment
- Enables controlled separation before re-entry

Materials

- **Rails:** Ti-6Al-4V titanium
- **Guide shoes:** Titanium with wear liner
- **Latch hooks/pins:** Titanium alloy
- **Adapter plate:** Ti-6Al-4V
- **Separation springs:** Titanium alloy

Benefits

- Secure launch attachment
- Controlled spacecraft separation
- Maintains deployment alignment
- Rail system protected inside thermal cavity

System Design

Dual-rail carriage mounted to Passive FRAM adapter plate

Key components:

- 2 parallel guide rails
- 4 guide shoes on pod keel
- 2 structural launch latches
- Spring-loaded separation pushers
- Recessed rail cavity under pod

Separation Sequence:

- Pod avionics activate
- Electrical umbilical disconnects
- Latches release
- Springs push pod away
- Pod slides along rails
- Pod clears rails → re-entry trajectory

Design Concept – Main Body

Purpose

The main body shell forms the primary aerodynamic outer mold line of the cargo return pod and supports the capsule's non-peak thermal regions during atmospheric re-entry.

Materials

- Carbon Fiber Reinforced Polymer (CFRP) outer shell
- Aluminum alloy internal support panels
- Ceramic insulation blankets between shell and internal structure

Benefits

- Reduced structural mass
- Improved aerodynamic stability
- Thermal protection for internal systems

Key Design Features

- Smooth aerodynamic surface
- Lightweight composite construction
- Internal insulation layer
- Integrated mounting points for bulkheads and internal frames

Design Rationale

- CFRP provides high strength-to-weight ratio
- Composite shell reduces overall capsule mass
- Aluminum internal panels allow mounting of avionics and internal hardware
- Insulation protects internal systems from thermal soak during re-entry

Design Concept – Under Belly & Nose

Purpose

The underbelly and nose of the capsule experience the **highest thermal loads during atmospheric re-entry**. These surfaces require dedicated **thermal protection materials** to prevent structural overheating.

Materials

- **PICA (Phenolic Impregnated Carbon Ablator)** heat shield
- **Titanium support plate** beneath TPS
- **Thermal insulation layer** between TPS and structure

Benefits

- Protects vehicle during **hypersonic re-entry**
- Prevents structural overheating
- Maintains integrity of cargo compartment

Design Rationale

- PICA is a lightweight ablative heat shield material
- Ablation removes heat by material sacrificially burning away
- Titanium support structure provides high temperature structural stability

Thermal Protection Zones

- Nose stagnation region — highest heating
- Flat underbelly TPS region — primary heat shield surface
- Lower side shoulders — moderate heating areas

Design Concept – Structural Frame

Purpose

The internal structural frame distributes **launch loads, rail attachment loads, and landing loads** throughout the capsule.

Materials

- **Aluminum alloy bulkheads**
- **Titanium keel beam**
- **Titanium rail attachment inserts**

Benefits

- High structural strength
- Efficient load distribution
- Protection of internal systems and cargo

Structural Components

- **Central keel beam** supporting rail interface
- **Five structural bulkheads** supporting shell and internal systems
- **Load transfer mounts** for parachute and separation hardware

Design Rationale

- Aluminum bulkheads provide **lightweight internal structure**
- Titanium keel beam handles **high localized loads**
- Structural layout prevents load transfer through **thin shell surfaces**

Key Load Paths

- Launch loads → keel beam → bulkheads → shell
- Rail interface loads → keel beam → main structure
- Landing loads → keel beam → frame system

Design Concept – Temperature Cargo Compartment

Purpose

The cargo compartment protects **temperature-sensitive payloads returned from the ISS**, including biological samples and scientific experiments.

Materials

- **6061-T6 Aluminum inner liner**
- **Aerogel insulation blanket**
- **Aluminized Multi-Layer Insulation (MLI)**
- **Phase Change Material (PCM) thermal packs**
- **Silicone hatch seal**

Benefits

- Maintains stable temperature during re-entry
- Protects sensitive scientific payloads
- Enables safe return of ISS experiments

Thermal Control Strategy

- Aluminum liner distributes heat evenly
- Aerogel insulation reduces heat transfer
- MLI reduces radiative heat gain/loss
- PCM maintains constant temperature during re-entry and recovery

Internal bay designed for payload:

622 mm × 470 mm × 279 mm

Payload mass: 72 lbs. (32.7 kg)

Additional Features

- Removable aluminum cargo tray
- Velcro restraint straps
- EVA foam padding
- Optional heater pads and temperature sensors

Design Concept – Parachute System

Purpose

The parachute recovery system slows the capsule during the final descent phase after atmospheric re-entry, enabling a **controlled and survivable splashdown** in the ocean.

Materials

- **Parachute canopy:** Kevlar ripstop fabric
- **Suspension lines:** Kevlar high-strength fibers
- **Deployment bag:** Nomex fabric
- **Bridle attachment hardware:** Titanium fittings
- **Parachute bay structure:** Aluminum alloy housing

Benefits

- Reduces landing velocity to safe levels
- Stabilizes capsule during descent
- Reliable passive recovery method
- Enables safe recovery of cargo and spacecraft

System Architecture

The recovery system uses a **two-stage parachute deployment sequence**:

Drogue parachute deployment

- Stabilizes the capsule
- Reduces velocity after peak heating phase

Main parachute deployment

- Large canopy significantly slows descent
- Reduces landing velocity to safe splashdown speeds

Deployment Sequence

- Capsule exits hypersonic re-entry phase
- Drogue chute deploys to stabilize vehicle
- Main parachute deploys at lower altitude
- Capsule descends under controlled velocity
- Splashdown occurs in designated recovery zone

Design Concept – Battery System

Purpose

Provides onboard power for avionics, separation systems, parachutes, flotation, cargo thermal control, and recovery operations. Designed to maintain critical functions for **at least 6 hours after splashdown**.

Materials / Components

- **Battery cells:** Aerospace-grade Lithium-ion battery pack
- **Battery enclosure:** Aluminum alloy housing
- **Battery management system (BMS):** Charge/discharge monitoring and protection
- **Charging interface:** Blind-mate charging connector integrated into the rail interface
- **Power distribution unit:** Regulated power bus and load control electronics
- **Wiring harness:** Shielded aerospace electrical wiring
- **Thermal protection:** Insulation blanket and optional heater pads

Benefits

- Provides **self-contained mission power**
- Maintains battery charge while attached to host spacecraft
- Supports **all deployment and recovery systems**
- Enables **minimum 6-hour post-splashdown survival window**
- Supports temperature-sensitive cargo protection

System Design

The pod uses a **self-contained rechargeable lithium-ion battery system** that is charged while attached to the host spacecraft. Once the pod separates for re-entry, the system transitions to **internal battery power**. Key components include:

- **Primary lithium-ion battery pack** for mission power
- **Battery management electronics** for safety and cell balancing
- **Blind-mate charging connector** for host spacecraft charging
- **Power distribution system** supplying avionics, deployment systems, and thermal control
- **Low-power survival mode** activated after splashdown

Power Loads Supported

The battery system supports:

Flight computer and avionics; Navigation sensors (IMU/GPS); Separation release system; Parachute deployment electronics; Flotation system inflation hardware; Recovery beacon transmitter; Cargo thermal management system; Health monitoring sensors

Power Operation Sequence

1. Pod attached → battery charging
2. Pod separates → internal battery power
3. Battery powers avionics and deployment systems
4. Parachute and flotation deploy
5. Survival mode power beacon until recovery

Design Concept – Recovery System

Purpose

The recovery beacon system allows the cargo return pod to **transmit its location after splashdown**, enabling recovery teams to quickly locate and retrieve the vehicle and its cargo within at least 6 hours after splashdown

Materials / Components

- **Emergency locator beacon:** Satellite-compatible distress transmitter
- **GPS receiver:** Integrated navigation receiver for position tracking
- **Beacon antenna:** two Low-profile omnidirectional antennas mounted in a beacon box
- **housing:** Aluminum or composite protective enclosure
- **Electrical interface:** Connection to the onboard battery system
- **Water detection sensor:** Trigger for automatic activation after splashdown

Benefits

- Enables **rapid recovery of the pod and cargo**
- Provides **precise GPS location after splashdown**
- Operates automatically without ground commands
- Low power consumption supports **extended post-landing operation**
- Improves safety and reliability of recovery operations

System Design

The recovery system uses a **GPS-enabled emergency beacon** integrated with the pod avionics. After splashdown, the beacon automatically activates and transmits the pod’s location to recovery teams.

Key Components

- **Satellite or radio distress beacon** for long-range recovery signaling
- **Integrated GPS module** for precise location reporting
- **Low-power electronics** to extend operation during the recovery window
- **Automatic activation sensor** triggered by splashdown
- **Backup manual activation command through avionics**

Beacon Operation Sequence

I. Pod separates and re-enters atmosphere
II. Parachutes deploy during descent
III. Pod splashes down in recovery zone
IV. Water sensor activates beacon
V. GPS determines location
VI. Beacon transmits position until recovery

Design Concept – Floatation System

Purpose

The flotation system ensures the capsule **remains upright and buoyant after splashdown**, protecting the cargo compartment from seawater and enabling safe recovery by the retrieval team.

Materials

- **Inflatable flotation bags:** Reinforced polyurethane or coated nylon fabric
- **Inflation system:** Compressed gas cartridge (CO_2 or nitrogen)
- **Float structure housing:** a mix of CFRP and High-Density Polyethylene
- **Sealing gaskets:** Silicone rubber seals

Benefits

- Prevents capsule submersion after landing
- Maintains upright orientation
- Protects sensitive cargo from seawater exposure
- Enables safe and efficient recovery operations

System Design

The flotation system includes **two deployable flotation bags** mounted near the upper sides of the capsule.

Key components include:

- **Inflatable flotation bags**
- **Automatic inflation mechanism**
- **Water stability control**

Deployment Sequence

- Splashdown sensors detect water contact
- Flotation bags automatically inflate
- Bags stabilize capsule orientation
- Capsule remains upright and buoyant
- Recovery teams retrieve capsule and cargo

Flotation Capacity

Designed to support the capsule with total estimated mass:

~105 kg vehicle mass + 32.7 kg cargo

Total supported mass capacity:

≈150 kg flotation capability